IMPROVEMENT and INDUSTRIAL UTILIZATION of SOYBEANS

Research under the Soybean Laboratory Program

Miscellaneous
Publication No. 623

U. S. DEPARTMENT OF AGRICULTURE

FOREWORD

A number of important agricultural problems are primarily regional in scope, as distinguished from others that are limited to individual States and still others that are of country-wide interest. To meet the need for research on such problems, the Bankhead-Jones Act of 1935 provided for regional laboratories, to be administered by the Secretary of Agriculture, which would mobilize scientific resources for a fundamental attack on some of the most important of these problems.

Nine such laboratories have been established. Each deals with a problem or group of problems selected in cooperation with the State agricultural experiment stations of the region as being among the most important faced by agriculture in that section of the country. The States cooperate with the Department in planning and carrying out the research program of each laboratory on a regional basis. At the same time the subjects under investigation are of importance in varying degrees to all major agricultural regions. The results obtained by the laboratories therefore contribute to agriculture on the national and local, as well as the regional level.

This publication is one of a series. Each describes the work of one of the Bankhead-Jones laboratories, covering the complete program, the results obtained to date, and the continuing research. Papers on various phases of their work have been published by all the laboratories as Department publications and in technical journals.

The laboratories and their locations are as follows:

U. S. Regional Vegetable Breeding Laboratory, Charleston, S. C.

U. S. Regional Pasture Research Laboratory, State College, Pa.

U. S. Regional Soybean Laboratory, Urbana, Ill.

U. S. Regional Swine Breeding Laboratory, Ames, Iowa.

U. S. Western Sheep Breeding Laboratory, Dubois, Idaho.

U. S. Regional Animal Disease Research Laboratory, Auburn, Ala.

U. S. Regional Poultry Research Laboratory, East Lansing, Mich.

U. S. Regional Salinity Laboratory, Riverside, Calif.

U. S. Plant, Soil, and Nutrition Laboratory, Ithaca, N. Y.

W. V. Lambert,
Administrator of Agricultural Research.

Cover Illustration.—University of Illinois building at Urbana where offices and laboratories of the United States Regional Soybean Laboratory are located.

Washington, D. C. Issued September 1947

For sale by the Superintendent of Documents, U. S. Government Printing Office
Washington 25, D. C. - Price 10 cents

CONTENTS

IMPROVEMENT AND INDUSTRIAL UTILIZATION OF SOYBEANS

Research Under the Soybean Laboratory Program[1]

Establishment of a new laboratory to study "America's fastest expanding crop" was announced by the Secretary of Agriculture on March 16, 1936. "Twelve North Central States and the U. S. Department of Agriculture have opened a cooperative soybean industrial research laboratory at Urbana, Ill.," the announcement reported. The 12 participating States were Ohio, Indiana, Illinois, Michigan, Wisconsin, Minnesota, Iowa, Nebraska, Kansas, Missouri, North Dakota, and South Dakota (fig. 1).

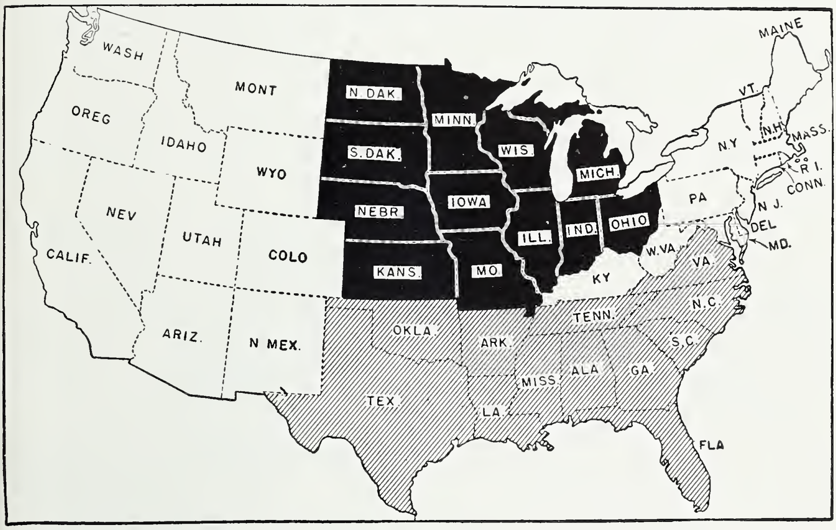

Figure 1.—The States originally cooperating in the work of the Soybean Laboratory are those shown in black. Since 1942 the shaded States also have been cooperating with the laboratory in its research program.

Representatives of the Department and of the experiment stations of these States had met in Chicago February 7, 1936, to give joint consideration to the establishment and planning of a regional laboratory under the provisions of the Bankhead-Jones Act. Suggestions for research received from the States were used in outlining a proposed program for the consideration of the joint conference, which recommended approval of a soybean laboratory for the region and agreed to the general objectives.

[1] Prepared in the Office of the Administrator of the Agricultural Research Administration in collaboration with those responsible for the research described.

BACKGROUND OF SOYBEAN PROBLEMS

During the period 1926–35 the acreage of soybeans harvested for beans increased from 466,000 to 2,915,000 acres, and the production of beans rose from 5,239,000 to 48,901,000 bushels. Much of this expansion took place in States of the north-central region. The research and educational programs of State agencies and the Department contributed to this growth. The availability of new varieties of soybeans suited to differences in soil fertility and length of growing season was an important factor in the expansion of production into new areas. The study and distribution by the Department of thousands of new introductions of soybeans from the Far East provided material for this expansion.

The demand for food and feed crops in the years 1915–25 had given considerable impetus to the growing of soybeans for hay and grazing, which created a demand for seed beans. As better adapted varieties were established, seed production expanded into new areas, and attractive prices for the seed stimulated seed growing in areas that had previously depended on outside sources.

The use of soybeans for hay and grazing familiarized many farmers with the crop. Soybeans proved resistant to drought and provided a legume for use on lands unsuited to the production of red clover. On other lands where red clover frequently failed, the soybean was used as a catch crop. It also fitted into the primary cropping system of certain areas of the region, replacing grain, particularly oats. The period 1925–35 was marked by diminishing export outlets for grain, and growers were looking for new crops.

According to the annual report of the Illinois Agricultural Experiment Station for 1935–36, on 102 farms in the heavy soybean-producing area in Illinois, soybeans in 1935 occupied 36 percent of the total farm area and 42 percent of the area in harvested crops, as compared with about 16 percent and 20 percent, respectively, in 1928 and 1929. This rapid increase came about largely because farmers substituted soybeans for a part of their grain crops. In 1928 and 1929 the acreage of soybeans on these farms was second to that in corn; in 1935 there was more land in soybeans than in corn.

Reduced domestic production of other oil-bearing seeds and increase of duty on imported vegetable oils were favorable to the expanding commercial production of soybeans for oil. Cottonseed production was down because of diminishing export outlets for cotton and increasing hazards from boll weevil in the cotton States, resulting in reductions in cotton acreage.

Prices in 1915 and 1925 were favorable to expansion in soybean seed production. The adaptation of the combine to harvesting and improvements in varieties and in cultural methods stimulated production of seed. By 1928 growing of soybeans for processing was accelerated in Illinois by an offer by processors of contracts for commercial seed production up to 50,000 acres with a guaranteed price of $1.35 per bushel for No. 2 beans delivered at two points in the State. These market contracts and the later development of a growers' marketing organization gave a measure of stability to commercial production.

When a soybean laboratory was under consideration in 1935, considerable industrial technology on the utilization of soybean products had already been developed. Industries had gained some experience through the use of limited domestic supplies and large importations of soybeans during World

War I. A measure of the previous developments in the technology of the crop is the fact that 206 patents were issued on soybean products and processes in the United States between 1905 and 1936.[2] The patents included 107 pertaining to food uses, 52 to general processes, and 47 to nonfood industrial processes. Various industries in the north-central region were ready to use the soybean and its products. The soap industry with its expanding markets, paint and varnish manufacturers, vegetable-shortening and oleomargarine processors, casein and glue producers, and plastics manufacturers were established in the region. There was no lack of an industrial market for soybean oil, and the demands for meal in industrial products and food were growing.

The background conditions which have been described were largely favorable to the expansion of the soybean crop. The crop and its associated industries, however, had made progress in the face of many difficulties, and the outlook in 1935 was far from favorable in all respects.

Returns to growers had been unsatisfactory. The Illinois Agricultural Experiment Station reported[3] that during the decade 1921–30 soybeans were less profitable on the better land of the Corn Belt than corn, wheat, alfalfa, or red clover, though they were more profitable than oats or timothy. It was further reported that "during this period the returns from soybeans, including seed and mill beans, and straw lacked 17 cents an acre of being sufficient to pay growing and harvesting costs and taxes and interest on the land." Varieties of beans better suited to industrial utilization and further economies in the cost of production were considered necessary. Those most familiar with the agronomic phases of the crop saw opportunities to improve its position through breeding and introducing varieties better adapted to the region and to industrial uses.

At the time of the establishment of the Soybean Laboratory, the expansion in processing facilities had kept pace with the increased production of beans, and the products were finding ready market outlets. The equipment and processes used had been developed for handling other oilseeds, however, and they needed adjustment to be effective in processing soybeans. Soybean products were supplying a market made available by the shortage of lard, cottonseed, flaxseed, and casein and were looked upon as inferior substitutes. If the primary products should regain their normal rate of production, it was feared that soybeans would lose this market. Those most familiar with the industry and its problems felt that the future competitive position of soybeans could be strengthened through improvement of the industrial processes and modification of the products. There was a need for adequate market grades as a basis for dealing with growers. Shortening made from soybean oil had poor keeping quality and unpalatable flavors. Soybean oil for paints and varnishes needed improvement in drying properties and uniformity of quality. Soybean protein was being used to some extent, but basic information on its recovery, natural properties, and opportunities for modification was largely lacking.

---

[2] Hennefrund, H. E., and Colvin, E. M. the soybean industry. U. S. Bur. Agr. Econ. Bibliog. No. 74, 474 pp. 1938. [Mimeographed.]

[3] Stewart, C. L., Burlison, W. L., Norton, L. J., and Whalin, O. L. supply and marketing of soybeans and soybean products. Ill. Agr. Expt. Sta. Bul. 386, pp. [425]–544, illus. 1932.

ORGANIZATION OF THE LABORATORY

In selecting the location for the Soybean Laboratory, the advantages offered by the University of Illinois at Urbana were considered outstanding. The University, through its research and extension programs, had successfully established a place for the crop in the agriculture of the State. Illinois, in the heart of the north-central soybean-producing area, grows more soybeans than any other State. The offer of laboratory space, storage facilities, plot land, and associated services by the University made possible the immediate establishment of the laboratory at Urbana.

Since the problems of soybean production and utilization required both biological and technological studies, two bureaus of the Department cooperated with the States in planning the research program of the laboratory. The Bureau of Plant Industry [4] cooperated in the development of plans for the study of factors influencing the production and quality of the crop, and the Bureau of Chemistry and Soils [5] contributed to the planning of research on the qualities of soybeans desired by industry and the development of industrial processes to extend the uses for soybean products.

The initial organization of the laboratory called for a director as administrative head and a staff of specialists in agronomy and chemistry. The agronomic work was integrated with the Department's soybean program in the Bureau of Plant Industry, and with work in the States by the establishment of cooperative agents in five States in the major soil and climatic areas where soybeans were produced.

The chemical personnel included as project leaders a chemical engineer to serve the processing requirements of the laboratory and to conduct research in this field, a chemist familiar with industrial plastics and other uses for plant proteins, an oil chemist, and an analytical chemist; and in addition, three associate chemists and a number of assistants. Under cooperative arrangements with the Indiana Agricultural Experiment Station, two cooperative agents were appointed for chemical research on soybean products in that institution.

The understanding between the 12 States and the Department provided for continued joint planning and coordination of the laboratory's research program for the broad regional attack on soybean production and utilization problems. State representatives designated by their respective experiment station directors were appointed collaborators by the Secretary of Agriculture. The collaborators and Department representatives functioned as a planning and integrating group. Representatives of the States agreed to assemble short abstracts descriptive of any work being carried on at their stations which pertained to soybeans.

On July 1, 1942, the research on utilization of soybeans and their byproducts, which up to that time had been carried on in the laboratory at Urbana, was transferred to the Northern Regional Research Laboratory at Peoria, Ill. The agronomic studies, including genetics, breeding, and physiology, were continued at the Soybean Laboratory and in the cooperating States. Chemical facilities to serve the breeding and physiological programs also remained in the Urbana laboratory. The soybean was designated as one of the farm commodities for study at the Northern Regional Research Laboratory, and the research program on industrial utilization

[4] Now Bureau of Plant Industry, Soils, and Agricultural Engineering.
[5] Now Bureau of Agricultural and Industrial Chemistry.

has been further developed there. As a result of this change the U. S. Regional Soybean Laboratory at Urbana was able to extend the cooperative breeding and research studies to the agricultural experiment stations of 12 Southern States.

THE COOPERATIVE RESEARCH PROGRAM

At the first meeting of the collaborators in Urbana on April 22, 1936, consideration was given to the further development of research plans. In fields of chemistry and chemical engineering four groups of projects were outlined. These included studies of (1) soybean oil in food and nonfood uses, (2) soybean meal as a source of industrial products, (3) chemical properties of soybeans and their products, and (4) engineering aspects of processing. Joint agronomic and chemical research was outlined to study the influence of differences in variety, soil type, soil treatment, and climate on the composition of the beans. Agronomic studies were directed to the further selection and improvement of varieties by breeding with special reference to regional adaptation and industrial uses. The soybean production studies were later supplemented with controlled physiological investigations to learn more about the influence of environment on the composition of soybeans, and with studies of soybean diseases and their control by breeding resistant varieties and by other methods.

The cooperative research planned with the Indiana Agricultural Experiment Station included studies of the chemistry of the phosphatides, sterols, and associated compounds of soybeans and of the isolation, identification, and characterization of the carbohydrates of soybeans.

ACCOMPLISHMENTS OF THE RESEARCH WORK

In reviewing the work and accomplishments of the U. S. Regional Soybean Laboratory, it should be remembered that its purpose was specific and that its progress was the result of the splendid cooperation of growers, processors, manufacturers, and educational and research forces in the region. Its founders planned "to obtain, through basic research, facts and materials applicable to the industrial utilization of the soybean and soybean products and to develop methods whereby these facts and materials may be utilized for the benefit of agriculture." The plans were unique at the time in that they proposed to integrate research on the production of a farm crop with research for its industrial utilization. It was expected that the closer association of these purposes would result in a clearer understanding of the factors which influence the industrial qualities of the crop. In the present summary of progress toward this end, consideration is given to improvements in and standardization of the crop as a source of industrial raw material, the advancement of basic knowledge of its components and properties, and the application of this knowledge to the manufacture of useful products.

Soybeans and Their Industrial Uses

The long and varied use of the soybean in the Orient has developed and preserved varieties suited to a broad range of climate and use. Some of those varieties had been introduced into the United States by representatives of the State experiment stations and were grown on limited areas prior

to 1900. The Department introduced a large number of varieties in 1898 and has continued to seek superior strains since that time. The careful study by W. J. Morse, of the Bureau of Plant Industry, of soybeans and their associated industries in the Orient in 1929–31 was fruitful in the selection of soybean varieties suited to special purposes and in the collection of accurate information on the processing and manufacture of soybean products. The results of this study proved valuable to the development of the Soybean Laboratory program and to the solution of emergency problems during World War II.

Previous studies of available varieties had given some measure of the differences in plant and seed characters of soybeans due to variety. Varietal differences in oil content, oil properties, and protein content had been observed, but the available information on varieties of soybeans adapted to the north-central region did not permit accurate predictions as to their quantitative or qualitative industrial properties. The cooperative research program, therefore, included plans for a systematic study of representative varieties to be grown under the various soil and climatic conditions in the region. These uniform variety tests have been conducted by the State agricultural experiment stations in Ohio, Indiana, Illinois, Iowa, and Missouri since the beginning of the cooperative program in 1936, and all of the North Central States have cooperated in this work since 1942. It was expected that agronomic records of the variety and environment correlated with chemical analysis of the seed would indicate differences due to variety and shed some light on the influence of environment, soil type, soil fertility, and seasonal climatic conditions on the industrial constitutents and their properties.

The initial variety studies of 1936 included the following 8 named varieties and one strain designated by number, arranged according to length of time required to mature, from 100 to 130 days: Mandarin, Mukden, Illini, Dunfield, Manchu, Scioto, T–117, Peking, and Boone. Plantings were made in uniform tests at 43 points representative of soybean-producing areas in Illinois, Indiana, Iowa, Missouri, and Ohio. Additional varieties and strains were included in these tests as promising selections were developed in the breeding program. The variety studies conducted each year since 1936 have provided helpful information on the adaptation of varieties in the region to industrial processing.

Protein Content of Soybeans

The crude protein content of the soybean, which normally ranges between 40 and 45 percent in commercial varieties, determines quite largely the value of soybean meal for feed and industrial purposes.

Samples of seed from each of the varieties grown in uniform variety tests at Ames, Iowa; Columbia, Mo.; Urbana, Ill.; Lafayette, Ind.; and Columbus, Ohio, during the 5 years 1936–40 were examined for crude protein content. The records for the varieties at all locations during the 5 years showed a mean protein content of 46.4 percent for Mandarin, the variety having the highest content, and 40.6 percent for Peking, the lowest. Of two important commercial varieties compared for protein content during the 5-year period, Dunfield was relatively low, with a mean of 41.4 percent, while Manchu had a mean of 44.1 percent.

In comparing the protein content of varieties grown in the five localities during the 5 years, it was found that seeds produced at Urbana were lowest,

with an average of 41.4 percent, and those produced at Ames were highest, averaging 43.5 percent protein. The average protein content of seeds from all localities was 42.9 percent. Reasons for differences between localities have not been fully determined.

Records of the protein content of varieties during the five seasons have made it possible to compare results between seasons, and temperature and rainfall records during each of the seasons have made possible the correlation of variation in protein content with differences in weather conditions. The average protein content for all varieties was highest in 1936 (44.4 percent) and lowest in 1937 (42.2 percent). The high protein content of 1936 is attributed, in part, to high temperatures during the summer and fall of that season.

Studies of the soybean in chambers (fig. 2) where light, temperature, and

FIGURE 2.—Culture chamber at the Soybean Laboratory where soybeans are grown under controlled environmental conditions.

humidity were controlled showed that seed of higher protein content was produced at the higher temperatures. In these studies the inherent characteristic of the variety was the most important factor in determining the protein content. Changes in soil, fertility, and season did not greatly influence the relative standing of the varieties with reference to protein.

Oil Content of Soybeans

Until recently the amount and quality of oil that could be recovered determined the commercial value of soybeans. As a rule the meal has been looked upon as a byproduct. Though the yield of oil is slightly less than one-sixth of the total weight of beans, the value of oil per pound is usually four to five times greater than that of the meal. For this reason, varieties and production factors were examined to determine their influence on oil content and yield (fig. 3).

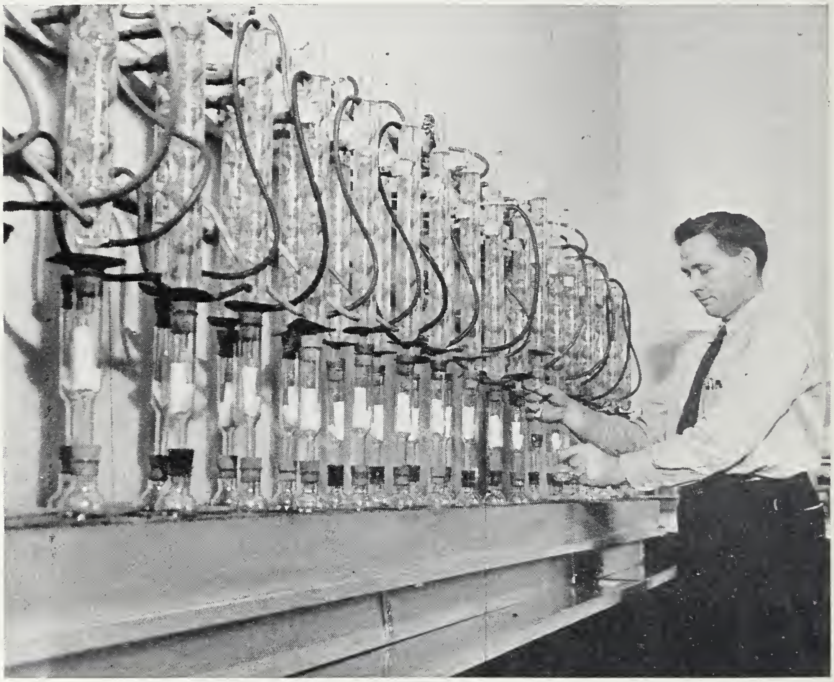

Figure 3.—Laboratory equipment for determining the oil content of soybeans of different varieties and strains.

Samples of beans from each of the varieties in the uniform variety tests of five States were examined for oil content during the 5-year period 1936–40. Peking had the lowest mean oil content with 17.07 percent, and Dunfield the highest with 20.97. The mean oil content for all varieties was 19.63 percent.

In the comparison of oil content by locality of growth it was found that the highest mean content—20.36 percent—was produced at Urbana, and the lowest—19.15 percent—was recorded for beans grown at Ames. The mean oil-content value for all localities was 19.63 percent. As a general rule, the higher levels of oil content are associated with lower protein content, and low oil content accompanies high protein content. The two localities in which the extremes of protein content were found also produced the extremes in oil content, in reverse order. Differences in soil-fertility level did not change the oil percentage of the plantings, though increasing the

fertility of poor land by adding manure and phosphoric acid resulted in increased yields.

During the first 5 years of study, differences in oil content between seasons were small. The highest percentage of oil—20.03 percent—was obtained from the 1939 crop, and the lowest—19.01 percent—was recorded for the 1940 crop. The mean value for the five seasons was 19.63 percent. The records of the 5 years' study indicate that variety was more important in influencing oil content than differences in soil fertility or seasons. It was also concluded that differences in climate were more important in their effects on oil content than differences in soil.

Because of its chemical and physical properties soybean oil can be used in both food and nonfood products. It has become a primary domestic source of oil for shortenings and oleomargarine. In industry it has found increasing use in the production of paints, varnishes, and other protective films.

An oil suited to the manufacture of paint is said to have good drying properties—the ability to form a firm film. The iodine number (the number of grams of iodine that 100 grams of oil will absorb) is used to estimate the drying properties of oil. Oils of high iodine number contain a greater percentage of film-forming materials and are better drying oils, while those having a lower iodine number are more desirable for food uses.

Information was obtained on the quality of the oil from the principal commercial varieties of soybeans grown under different soil and climatic conditions in the north-central region. Results from examination of several hundred samples of soybean oil gave a range in iodine number of 103 to 151. It was found that variety or genotype determines more largely than any other factor the iodine number of soybean oil. The variety Dunfield, for example, produces oil with an iodine number of 124, whereas Peking produces oil with an iodine number of 137 under the same environmental conditions.

The environment, especially the temperature at time of seed development in the pod, was also found to affect the iodine number of soybean oil, high temperature during seed development producing an oil with a low iodine number and low temperature an oil with a higher iodine number. The influence of atmospheric temperature on iodine number and physical properties of the oil was verified by studies in the greenhouse, where temperatures were under careful control. The results of the studies of production factors influencing soybean-oil quality indicate that oil for special uses may be produced by selecting varieties having the desired quality and by scheduling seed development to coincide with periods of low or high temperature.

Improvement of Soybean Varieties

The uniform variety tests of the principal commercial varieties of the region and associated chemical studies have established a background of information on the adaptation and industrial properties of available varieties. The results have helped in setting up standards for varieties suited to the various sections of the region. Some varieties have shown excellent agronomic qualities but are low in industrial qualities; some have one or two good industrial qualities, with others poorly developed. As a general rule, high protein is associated with low oil content. Since protein and oil are both important, it is desirable to have varieties that will produce the maximum of both.

The cooperative functioning of the uniform variety tests is illustrated in

the introduction and evaluation, agronomically and chemically, of such new varieties of soybeans as Gibson, Patoka, and Earlyana, selected by the Indiana Agricultural Experiment Station, and the Mukden, selected by the Iowa Agricultural Experiment Station. Gibson and Patoka have shown special adaptation to southern Indiana because of their higher yield and better industrial qualities than previously grown varieties. It is reported that these two varieties are adapted to an area in southern Indiana which normally grows 200,000 acres of soybeans (fig. 4).

FIGURE 4.—Studying the growth of different varieties of soybeans in a nursery at Lafayette, Ind.

The Richland and Earlyana varieties have largely replaced the Mukden, which was quite generally grown in northern Iowa and southern Minnesota.

The improvement of soybean varieties for the north-central region has been a primary objective of the agronomists who are participating in the cooperative program of the Soybean Laboratory. Through the use of new introductions, selections, and hybridization, they have sought strains that give higher yields, are resistant to lodging of plants and shattering of seed, bear sound, well-formed yellow seed, and have high oil and protein content. Variation in length of growing season required the selection of varieties that would mature in 85 days in the northern part of the region and in 140 days in the southern part. Plantings of thousands of introductions and selections along with standard varieties have been made to improve the economy and quality of production.

Definite progress has been made in the development of strains better suited to the principal producing areas of the region. One of these strains, Richland, selected by the Indiana Agricultural Experiment Station from a U. S. Department of Agriculture plant introduction, is particularly adapted to soil of high fertility because of its upright habit of growth and resistance to lodging. Earlyana, another variety selected by the Indiana station and established by the cooperative program, is 4 or 5 days earlier than Richland and is especially adapted to the less fertile soils of the northern part of the soybean-producing area.

The New Lincoln Variety

One of the most important achievements of the cooperative work has been the development of the Lincoln soybean (fig. 5). This strain is thought to be from a natural cross between a white-flowered strain of Mandarin and the Manchu soybean. It was discovered by the Illinois Agricultural Experiment Station in 1934 and selected by the Soybean Laboratory because of its outstanding yield and high oil content. The Lincoln is adapted to the areas where Illini and Dunfield are generally grown and is rapidly replacing these varieties. In 49 trials during 4 years in 5 States, Lincoln has averaged over 5 bushels per acre higher than the average of Illini and Dunfield. The oil content of this new variety is slightly higher than that of Dunfield and Scioto, the best in oil of the present commercial varieties, and over 2 percent above that of Illini. Lincoln has shown better lodging resistance than Illini and Dunfield and has excellent seed quality. Approximately 8,000,000 bushels of the Lincoln variety were produced in 1945, of which 2,033,333 bushels were officially certified for seed purposes.

FIGURE 5.—A field of Lincoln soybeans in southern Iowa.

Extending the Range of Soybean Production

The cooperative program of breeding and testing has shown that the limits of successful soybean production may be pushed northward in Michigan, Wisconsin, Minnesota, and the Dakotas through the use of new early strains such as Manchu No. 3, Manchu No. 606, Mandarin No. 507, and Flambeau, all developed by the Wisconsin Agricultural Experiment Station, and Manchukota, originated by the South Dakota Agricultural Experiment Station. Flambeau, an extra early variety developed at the Branch Experiment Station at Spooner and released by the Wisconsin station in 1945, gives promise of being the most productive variety for northern Wisconsin. Mandarin (Ottawa), a selection from the Mandarin variety by the Central Experiment Farm of Ottawa, Canada, has also given promising results in areas where early varieties are required. Boone, a selection of the Missouri Agricultural Experiment Station from a Department of Agriculture introduction, is gaining favor in that State.

In addition to new varieties developed through introductions and selections, promising strains have been developed from crosses designed to combine the good qualities of two or more varieties. A large number of crosses have been made between strains differing in earliness that are high yielding, resistant to lodging, and high in oil content, and some of these show promise for the northern area of the region.

Basic Information on Varieties and Strains

Tests of standard soybean varieties made over a long period under various climatic and soil conditions in the north-central region have yielded agronomic and chemical information by which to appraise their value for the farm and for industrial use. Records of similar tests of the progeny of crosses between these varieties have given a measure of the ability of the variety to transmit its quality and the extent to which a recombining of the good qualities of two or more parent varieties may be expected. This information is basic to future improvement of varieties suited to special purposes.

The free exchange of seeds from promising strains selected by each of the cooperating agencies has hastened the evaluation and establishment of superior strains in the region. During the period 1930 to 1940 the average yield of oil per bushel of soybeans was increased approximately 1 pound. This increase in yield added more than 100 million pounds of much-needed oil to the processed crop of 1943. The increase was due in part to the more general use of improved varieties of higher oil content.

The basic studies with many varieties and strains of soybeans have identified superior qualities in certain lines. Some have a desirable habit of growth, others have a favorable growing period, and a few are superior in yield and quality of seed. Strains differ in the oil and protein content of the seed and the properties of these constituents. Differences are also found in relative resistance to the various diseases of soybeans. The desired qualities are seldom combined in a single variety. In breeding varieties to meet special purposes it is often desirable to combine the good qualities found in two or more existing varieties. With this purpose, crosses have been made between varieties that possess the qualities desired. Segregates from these crosses are now being studied in field nursery plots, and some of them give promise of furnishing new lines superior to those now being grown.

Physiological Studies

Careful observations have been made of responses in growth and composition of soybeans grown in the greenhouse under controlled conditions of light, nutrition, temperature, and moisture. The results of these studies have given a background of information for interpreting the influence of environment and differences in seasonal conditions on growth and composition.

Disease-Control Studies

Continued intensive production of soybeans in the region has been accompanied by associated hazards. Each succeeding year has found an increasing incidence of diseases caused both by micro-organisms and by nutritional deficiencies in the soil. Specialists of the States and the Department have planned a cooperative program to reduce losses from disease. The scientific resources of the laboratory and the region are being used in deter-

mining the nature and cause of the various diseases, the extent to which they live in the soil or in the seed, the relative resistance of varieties and strains, and means of control (fig. 6).

FIGURE 6.—Examining a soybean plant that has been inoculated with a known disease and grown under controlled conditions so that the symptoms of the disease can be studied.

Extension of the Cooperative Program to the South

The original cooperative soybean program included the 12 North Central States. Since 1942, the program has been extended to 12 Southern States—Alabama, Arkansas, Florida, Georgia, Louisiana, Mississippi, North Carolina, Oklahoma, South Carolina, Tennessee, Texas, and Virginia.

The extended program is concerned with studies of factors that influence growth, yield, and composition of soybeans, improvement of varieties, and control of diseases. Observations are being made on the influence of variety characteristics, differences in soil fertility and climate, and cultural practices on production and quality of the crop. Selections are being made from hybrids and other plant materials that have shown superior qualities. Control of soybean diseases is sought through selection of resistant strains.

Under the cooperative program in the South, uniform soybean nursery tests were conducted at 52 points in the region during the 3 seasons 1943 through 1945. The length of frost-free periods for growing soybeans in

741870°—47——3

this region ranges from about 100 days in the mountain area to 180 days along the Gulf coast. In the northern part of the region, Ogden, Volstate, and Roanoke varieties have proved superior to varieties previously grown for industrial purposes. In the southern part, two new Louisiana varieties, Pelican and Acadian, are replacing Otootan, Avoyelles, and Palmetto for industrial and forage use.

Storage of Soybeans

Much of the soybean crop is moved to market soon after harvest, and large quantities of beans are held in storage at the mill. High humidity at harvesttime, as well as the necessity of harvesting immature beans caught by early frost, usually results in a crop of high moisture content. Large quantities of wet beans in storage may undergo heating and deterioration. Early in the planning of the cooperative research program this was recognized as a problem requiring study, and it was covered by a cooperative agreement between the Bureau of Chemistry and Soils (now Agricultural and Industrial Chemistry) and the Minnesota Agricultural Experiment Station.

The studies made included laboratory experiments designed to measure carefully the behavior and changes in stored beans and related observations under commercial storage conditions. Under controlled laboratory conditions it was found that rising temperature in soybeans of high moisture content was associated with increasing activity of micro-organisms, measured in terms of carbon dioxide given off. The results of practical value to soybean growers and those engaged in commercial storage showed that soybeans intended for seed purposes and requiring storage during warm weather or for long periods should contain not more than 10 percent moisture.

Soybeans harvested during wet weather should be artificially dried.

Soybeans in market grade No. 1 may be stored under most conditions; grade No. 2 may be safe under most conditions of storage, but for a shorter time; grades Nos. 3 and 4 involve a greater storage risk and should be stored only for short periods at low temperatures. When soybeans are stored at the high moisture content permitted in grades 3 and 4, temperatures should be closely watched and the beans moved when any heating is observed. Damage can occur without excessive heating.[6]

Establishment of Standards and Studies of Composition and Use

Though soybeans had been used by industry for a long time, adequate market grades had not been established when the cooperative research program began in 1936. Standards of seed quality and analytical methods for estimating industrial values had not been developed. In view of the growing trade in beans, it was essential to the grower and the processor that more precise measures of value be established. It was also anticipated that evaluation of large numbers of samples would be required in connection with the studies of varietal and environmental effects.

Improvements in methods and technique were rapidly introduced through cooperation with national scientific organizations responsible for the adoption of official methods. A group of Soybean Laboratory workers took an active part in the development by the American Oil Chemists' Society of methods for estimating refining losses in soybean oils separated by the

[6] From Ramstad and Geddes, The Respiration and Storage Behavior of Soybeans. See citation in list of publication, p. 25.

hydraulic-expeller and solvent extraction methods. Members of the staff participated in the work of the Soybean Analysis Committee of the American Oil Chemists' Society, one serving as chairman. Referees of the Association of Official Agricultural Chemists were given cooperation in their studies of analyses for ash and oil content of beans and their search for methods of detecting soybeans and soybean meal in other food products. A worker of the Soybean Laboratory familiar with soybean plastics cooperated with the Committee of the American Society for Testing Materials in developing tests for plastics which would more definitely evaluate their usefulness.

As a result of the examination by the laboratory of a large number of soybean samples of known history, a wealth of information has been accumulated on the chemical composition of normal and subnormal soybeans. For no other industrial crop of the United States is there such a background of correlated agronomic and chemical data. The small group of scientists assigned to the improvement of analytical methods and the study of the composition of soybeans and the properties of their products has made valuable contributions to the advancement of production, marketing, and industrial utilization of this crop.

Research Services to Growers and Processors

The practical value of the Soybean Laboratory to growers and processors is illustrated by the services rendered during the marketing season of 1939. Because of an early frost a large number of green beans were harvested. When the beans were processed the green color was carried over into the oil, and the soybeans were heavily penalized by being graded as damaged beans. The Soybean Laboratory demonstrated that the oil content had not been reduced and that the green color could be removed by proper bleaching. These results were corroborated by the processors, and the discounts due to grade were revised from as much as 60 cents a bushel to only a few cents.

The engineering section of the Soybean Laboratory conducted an economic survey of the oil-mill industry with special reference to the costs of processing and distribution of soybean products in comparison with competitive materials. Members of the engineering staff visited the processing plants in the commercial soybean-producing areas of the region and obtained information on the capacity, efficiency, equipment, storage capacity, and days per year in operation for each plant. This information was of utmost importance in the governmental mobilization of resources to meet the emergencies of defense and war. In 1941, when the need for vegetable oils and meal became critical and processing facilities were inadequate, members of the staff worked out plans for increasing the crushing capacity of mills with the minimum use of scarce war materials.

Information developed by the laboratory became increasingly useful to the growing soybean industry. Many companies sent members of their research staffs on regular visits to the laboratory to discuss its current research and to obtain help on specific problems. Assistance was given groups and individuals who were contemplating entering the processing field. Several such groups who came for engineering and technical advice later erected and operated successful processing plants. Other individuals and groups who had considered starting new plants were saved from probable financial loss by the technical and economic analyses made for their specific cases.

The Soybean Laboratory has served those engaged in soybean research and industry by bringing together summaries of scientific information bearing on the technology of soybeans and their products. These summaries, which have included both domestic and foreign sources of information, cover such subjects as molecular distillation, soybean protein, soybean chemistry and technology, and processing problems.

Improving Industrial Products From Soybean Meal

Two broad studies were made on the protein of soybean meal. One sought information on its basic chemical nature and properties, and the other applied these findings to utilization. The studies were conducted concurrently so that new basic information advanced the applied studies, and improvements in industrial processes found ready practical use in industry.

Exceptional progress in the utilization of soybeans for the higher industrial purposes has followed the development of basic knowledge of the chemical and physical properties of their constituents (fig. 7). Soybean

Figure 7.—Making a chemical analysis of some of the constituents of soybeans. The chemical composition of soybeans is an important index to their potential uses.

protein was in industrial use prior to the establishment of the Soybean Laboratory, but the empirical methods used in its extraction had not materially advanced the efficiency of the process used. Those who planned the research of the laboratory were of the opinion that current methods for the processing of soybean meal and its protein could not be accepted as effective or be improved without more information on the principles

governing solubility and dispersion of the protein. Extensive studies, therefore, were conducted on the water solubility of soybean protein, its dielectric constant, and the effect of acids, bases, salts, and specific reactions upon its recovery. The results contributed greatly to the fundamental knowledge of this protein, and made possible economies in its extraction.

Through these chemical and physical studies of factors that influence the solubility and precipitation of soybean protein, the Soybean Laboratory not only contributed to fundamental knowledge but supplied a guide for the practical recovery of the protein. On the basis of this information, one large producer of commercial protein changed his manufacturing procedure. Three other manufacturers who obtained the published results installed pilot plants for the study of applied phases of soybean-protein production. The scientific value of these studies has been recognized by other research agencies that sought to find similar processes for the extraction and use of cottonseed and peanut protein.

Associated studies on the utilization of soybean meal and protein in industrial products were further directed to the preparation of plastics (fig. 8), paper sizing, and improvements in processing by the dispersion of

Figure 8.—Soybean flakes freed from oil and ready to be made into a plastic material by the use of chemicals, pressure, and heat.

protein in formaldehyde. New developments in this work were called to the attention of manufacturers as soon as commercial application seemed feasible. As a result soybean protein in various forms soon appeared in standard molding powders of the Bakelite type, and the fact that the powders contained soybean protein was used as a selling point. Direct technical

aid to manufacturers who were already using them in plastics made possible a greater use of soybean products.

Scientists of the Soybean Laboratory were the first to point out that the residue or mash remaining after the extraction of protein was superior to ordinary soybean meal for use in plastics because its water-soluble fraction had been removed. This apparently simple discovery of the properties of the residue is of importance in the manufacture of isolated protein as well as of plastics possessing superior physical properties and greater resistance to moisture. It was found that the residue meal could be used to replace a part of the wood flour and phenolic resin in the manufacture of phenolic-type plastics. A series of light-stable dyes for the soybean phenolic plastics was found, and these proved of particular interest to one large plastics manufacturer.

The results of the laboratory's studies on production of soybean protein for sizing and adhesives were also of practical value and found ready acceptance by industry. Improved methods of extraction and dispersion proved of particular interest to the processors of solvent-extracted soybean meal. One processor reported that the laboratory's method was being used in the production of more than a ton a day of soybean protein for use in sizing paper. The usefulness of this protein as an adhesive in paper coatings was enhanced by the discovery that bleaching it with the sodium or zinc salt of dithionous acid ($H_2S_2O_4$) produced a coating superior to casein in brightness and whiteness. In the search for other applications, preparations were made for dressing and coating leather. These were introduced to the tanning industry, and one of the plants that adopted the process reported that the soybean-protein finish for leather was the best they had used. The results of the laboratory's work on soybean-protein dispersion and the use of soybean meal with phenolic resin to make waterproof glue proved very useful to plywood manufacturers during the war.

Another outgrowth of work at the laboratory was the preparation of textile fibers from soybean protein. The fiber produced is comparable to commercial casein fiber. The research associated with its development has advanced the basic knowledge of soybean protein and its processing for textile fibers. The war limited the use of soybean oil meal and protein for many industrial purposes because of the need for protein feeds. Many of these developments will now find use in manufacturing programs.

Improving Industrial Products From Soybean Oil

The Soybean Laboratory has sought to develop a better understanding of the chemical and physical properties of soybean oil and its components. The research included examination of the natural properties, the nature of component oils, and the reaction of these oils to methods of processing and treatment for modification. The properties and reactions observed were examined with reference to their application to improve food and nonfood industrial uses. When the laboratory was established in 1936, soybean oil occupied the position of a substitute on the vegetable-oil market. Though more than three-fourths of that produced was used in food products such as shortenings, margarine, and salad oils, it did not possess superior qualities for these purposes. Approximately 9 percent of the soybean oil produced commercially was used in paints, varnishes, and other protective coatings, but it was being used as a substitute for the better film-forming oils. These outlets represented large potential markets if objectionable qualities of the oil could be modified.

Quick-drying oils, those which form tough films quickly when used as surface coatings, were needed from domestic sources. Such oils were being imported by the paint industry at costs greater than current prices of soybean oil, which, because of its slow drying, was used only as an inferior substitute. If its drying qualities could be improved, there was a potential market for it in the higher value uses. As already mentioned, the drying quality of the oil, measured by iodine number, had been improved; but this was not enough. To further change its drying qualities, the laboratory sought to modify the oil by physical and chemical treatments, while studies of its natural properties were continued. The results have demonstrated the advantages of soybean oil in protective coatings (fig. 9). Proof of the durability of paints made from soybean oil has done much to improve its standing for this use.

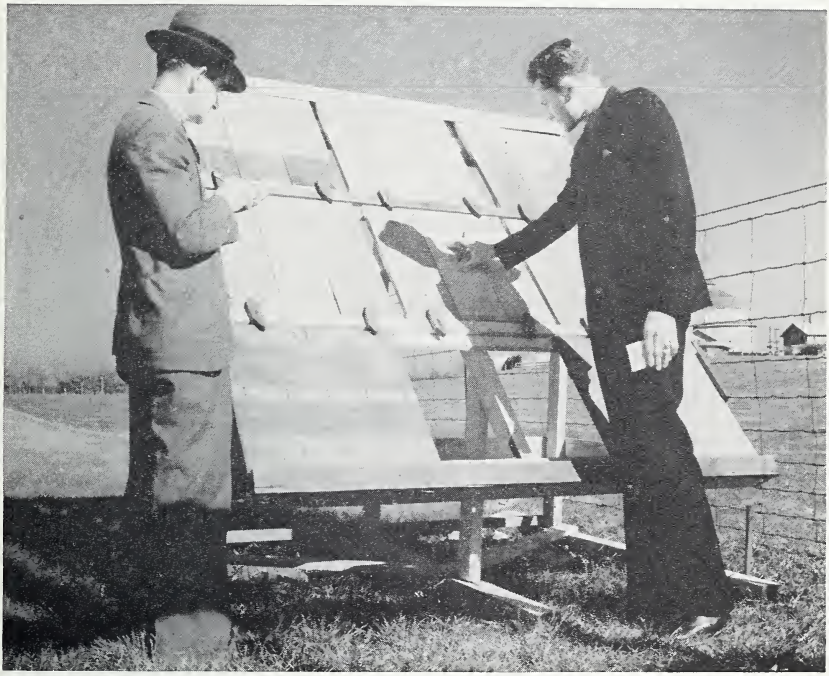

FIGURE 9.—Inspecting test panels treated with soybean-oil varnish and exposed to the weather on a 45° rack.

Industries using soybean oil in the preparation of food products found that the foods developed disagreeable odors and flavor during storage. If the laboratory could discover means of removing the unstable constituent of soybean oil or could modify the oil so that the objectionable change would not take place, then soybean oil might find expanding use in food products. The laboratory used a large part of its resources to attain this purpose.

The development of unfavorable odor and flavor during storage has been called reversion and rancidity. These undesirable qualities for food products could be reproduced at will, but little was known of the chemical nature of the changes that produced them. They were thought to be

associated with oxidation, however, and the solution was sought in the possibility that one constituent was more subject to oxidation than others. Some workers found that certain vegetable oils deteriorate more slowly than others and attributed this to the presence of natural antioxidants in these oils. Previous workers had attempted to develop methods for measuring the progress of oxidation and the associated chemical changes in the oil. In trying to discover a chemical basis for these changes in soybean oil, workers at the Soybean Laboratory examined the established methods of measuring the stability of oils. A method using methylene blue as an indicator of reduction by oxidation was found most useful for the purpose.

This principle was used in devising an apparatus that supplied greater control of light, temperature, and infrared radiation and that was also equipped with a light meter which gave more precise measures of changes in transmitted light. The equipment was useful in determining the relative stability of samples of oil of known history. Through its use the influence of various steps in processing and the effects of processing methods on relative stability were compared. These and related studies in the processing industry have done much to reduce deterioration due to improper processing and refining. The problem has not been solved, however, since complete information on the chemical reactions involved in reversion and rancidity is still lacking and the nature and functioning of natural antioxidants are not fully understood. Active research toward these objectives is in progress at the Northern Regional Research Laboratory.

The use of soybean oil in protective coatings was materially advanced by research at the Soybean Laboratory and by associated cooperative utility tests. All available opportunities were used to test the service given by special coatings compounded from soybean oil. Cooperative work with the Chicago Paint and Varnish Production Club, the Federal Bureau of Standards, the National Paint, Varnish, and Lacquer Association, and the Norfolk Navy Yard helped to demonstrate its value and gave confidence in its use. In cooperation with the highway division of a midwestern State, applications of soybean oil paints are under test for traffic markers. As a result of the various tests and demonstrations, soybean oil has been more generally accepted by the paint industry and consumers. In recognition of its quality, Government specifications on water paints were revised to permit the use of soybean products.

In a study of the chemical composition of a series of soybean oils with iodine numbers varying from low to high the laboratory found that the percentages of linolenic acids increased in a fairly regular manner with increase in iodine number, while the percentage of oleic acid decreased. In subsequent studies it was found possible to separate these fractions of the oil into one portion having a relatively high iodine number and another portion with a low iodine number. The fraction having the higher iodine number (175) proved superior to linseed oil in drying qualities. The fraction having low iodine value proved superior to the whole oil for the manufacture of shortening. It can be hydrogenated to a lower iodine number to obtain a given consistency and a more stable product.

With importations of drying oils practically cut off during World War II, special efforts were made to develop practical methods of separating the quick-drying and slow-drying fractions of soybean oil to meet essential war requirements. Other workers had demonstrated the use of selective solvents in separating fractions from crude petroleum, so solvents were tested to find one suited to the separation of the fractions of soybean oil. As a

result an efficient solvent was developed, and research is now under way to design processing equipment that can be used by the industry. This work has been continued in the Northern Regional Research Laboratory in Peoria since 1942.

Most raw materials are complex substances containing many distinct constituents, some of which have special commercial value because of their chemical and physical properties. Coal, with its great variety of products, is a familiar example. The vegetable oils are complex in that they contain constituents varying in physical and chemical properties. The Soybean Laboratory has given time to the study of the components of soybean oil and their characteristics and to means of isolating them in relatively pure form. The laboratory developed methods for applying the liquid-liquid process for separating the components of mixed methyl esters of soybean acids, and a patent covering this discovery was assigned to the Secretary of Agriculture. These studies were extended to pilot-plant tests to develop economical methods of separation that could be applied to commercial operations. Supplemental studies directed to this purpose took advantage of differences in the reaction of the components of soybean oil to temperature. At low temperatures certain components crystallized while others remained liquid, and at high temperatures separations could be made because of differences in volatility. Much was done by the Soybean Laboratory to indicate the principles involved in the separation of valuable components of soybean oil. There still remains the problem of applying these principles to commercial production, and this is now receiving attention in the Northern Regional Research Laboratory.

The history of industrial development contains many examples of economies in the processing of raw materials resulting from more complete utilization of byproducts. The fuller utilization of byproducts has usually come with the advancement of basic chemical and physical knowledge of their properties. Studies of the byproducts of soybean-oil refining were conducted with this purpose in mind. In refining crude soybean oil a yellowish-brown waxy substance is removed. This byproduct represents about 2 percent of the crude oil and consists of phosphatides, lecithin, and cephalin. Though this material has been used in various food products and has other uses, its properties justify further investigation. When the research program for soybeans was developed, cooperative agreements with the Indiana Agricultural Experiment Station provided for limited studies of sterols, which had been found associated with the phosphatides. It was also planned to separate and study the materials which make up the crude phosphatides of soybean oil.

This work was undertaken at the Indiana Experiment Station as a part of the regional cooperation. Previous independent studies of the Indiana Experiment Station had developed an effective method for the separation of an adsorbent (patented by Kraybill, Brewer, and Thornton, 1939, Patent No. 2,174,177). In the further development of this work it was found possible to separate fractions of the phosphatides from the adsorbent by the successive use of organic solvents differing in their selective properties. Basic knowledge of the properties of the materials thus derived from the phosphatides was advanced by chemical and physical examination.

Associated studies of phosphatides and other materials separated from crude soybean oil by adsorption with aluminum silicate indicated that approximately half the sterols could then be removed from the adsorbent by extracting with acetone. This produced a concentrate containing 15 to 20

times as much sterol as the crude soybean oil. The mixed sterols crystallized readily and were recovered by filtration. These sterols are of particular interest because they contain commercial quantities of stigmasterol, a chemical used in the synthesis of the sex hormone progesterone. The results of these studies will contribute to the domestic production of this chemical and to the utilization of the byproduct phosphatides.

Because of the transfer of the technological research of the Soybean Laboratory to the Northern Regional Research Laboratory in Peoria, Ill., July 1, 1942, this phase of the work is covered only up to that time. The workers in the biological program of the U. S. Regional Soybean Laboratory at Urbana and the technological group now engaged in research at the Northern Regional Research Laboratory in Peoria continue to cooperate in matters of mutual interest.

PUBLICATIONS OF THE SOYBEAN LABORATORY AND COOPERATORS

Allen, D. I. differential growth response of certain varieties of soybeans to varied mineral nutrient conditions. Mo. Agr. Expt. Sta. Res. Bul. 361, 43 pp., illus. 1943.

Allington, W. B. soybean disease investigations at the u. s. regional soybean laboratory. Soybean Digest 4(11): 60, 65. 1944.

——— wildfire disease of soybeans. Phytopathology 35: 857–869, illus. 1945.

——— brown stem rot of soybean caused by an unidentified fungus. Phytopathology 36: 394. [Abstract.] 1946.

——— bud blight of soybean caused by the tobacco ring-spot virus. Phytopathology 36: 319–322, illus. 1946.

——— soybean diseases in the cornbelt region in 1945. Soybean Digest 6 (11): 48, illus. 1946.

——— and Feaster, C. V. the relation of stomatal behavior at the time of inoculation to the severity of infection of soybeans by xanthomonas phaseoli var. sojense (hedges) (starr) burk. Phytopathology 36: 385–386, illus. 1946.

——— Kent, G. C., Tervet, I. W., and Koehler, Benjamin. 1943 results of uniform seed treatment tests on soybeans. Plant Dis. Rptr., Sup. 145: 76–79. 1944.

——— Kent, G. C., Tervet, I. W., and Koehler, Benjamin. results of the uniform soybean seed treatment tests in 1944. Plant Dis. Rptr., Sup. 159: 220–224. 1945.

Beckel, A. C., Brother, G. H., and McKinney, L. L. protein plastics from soybean products. relation of water content to plastic properties. Indus. and Engin. Chem. 30: 436–440, illus. 1938.

——— Bull, W. C., and Hopper, T. H. heat denaturation of protein in soybean meal. Indus. and Engin. Chem. 34: 973–976, illus. 1942.

——— and Cartter, J. L. the effect of variety and environment on the equilibrium moisture content of soybean seed. Cereal Chem. 20: 362–368, illus. 1943.

——— and Earle, F. R. a study of the moisture in soybeans. Indus. and Engin. Chem., Analyt. Ed. 13: 40–43, illus. 1941.

——— and Hopper, T. H. moisture content of soybean oil meals. Indus. and Engin. Chem. 33: 1448–1452, illus. 1941.

——— and Sharp, A. G. continual observation of changes in weight at oven temperatures. an apparatus for use in the study of drying rates and in the oxidation of oils. Indus. and Engin. Chem., Analyt. Ed., 12: 45–47, illus. 1940.

——— Sharp, A. G., and Milner, R. T. apparatus for determining moisture by the distillation method. Indus. and Engin. Chem., Analyt. Ed. 11: 425–426, illus. 1939.

Becker, H. C., Milner, R. T., and Nagel, R. H. a method for the determination of nonprotein nitrogen in soybean meal. Cereal Chem. 17: 447–457, illus. 1940.

Bickford, W. G. the stability of vegetable oils. iv. flavor reversion in soybean oil. Oil and Soap 18: 95–98, illus. 1941.

——— Anderson, Scott, and Markley, K. S. the stability of vegetable oils. i. the spectral transmittance of soybean oils. Oil and Soap 17: 138–143, illus. 1940.

——— Anderson, Scott, and Markley, K. S. the stability of vegetable oils. iii. investigation of the effect of radiation on the methylene blue-oil system. Oil and Soap 17: 252–256, illus. 1940.

——— Dollear, F. G., and Markley, K. S. the effect of hydroxyl groups on the apparent diene values of vegetable oils and fats. Amer. Chem. Soc. Jour. 59: 2744–2745. 1937.

BICKFORD, W. G., DOLLEAR, F. G., and MARKLEY, K. S. THE EFFECT OF HYDROXYL GROUPS AND ACETYLATION ON THE APPARENT DIENE VALUES OF SOYBEAN AND OTHER VEGETABLE OILS. Oil and Soap 15: 256–259. 1938.

——— and MARKLEY, K. S. THE STABILITY OF VEGETABLE OILS. II. APPARATUS FOR DETERMINATION OF THE RATE OF FADING OF METHYLENE BLUE-FAT SYSTEMS. Oil and Soap 17: 232–240, illus. 1940.

——— KRAUCZUNAS, P., and WHEELER, D. H. THE REACTION OF NONCONJUGATED UNSATURATED FATTY ACID ESTERS WITH MALEIC ANHYDRIDE. Oil and Soap 19: 23–27, illus. 1942.

BROTHER, G. H. CASEIN PLASTICS. *In* Sutermeister, Edwin, and Browne, F. L., Casein and Its Industrial Applications, Ed. 2, Chap. 7, pp. 181–232, illus. New York. 1939.

——— PLASTIC MATERIALS FROM FARM PRODUCTS. Indus. and Engin. Chem. 31: 145–148, illus. 1939.

——— CASEIN PLASTICS. Indus. and Engin. Chem. 32: 31–33, illus. 1940.

——— and MCKINNEY, L. L. DEVELOPMENT OF SOYBEAN PROTEIN AS A POSSIBLE BASE FOR PLASTIC MATERIAL. Brit. Plastics and Moulded Prod. Trader 10: 248–251, illus. 1938.

——— and MCKINNEY, L. L. PROTEIN PLASTICS FROM SOYBEAN PRODUCTS: ACTION OF HARDENING OR TANNING AGENTS ON PROTEIN MATERIAL. Indus. and Engin. Chem. 30: 1236–1240, illus. 1938.

——— and MCKINNEY, L. L. SOYBEANS. SOME POSSIBILITIES IN THE PRODUCTION OF PROTEIN PLASTIC MATERIAL FROM SOYBEANS. Mod. Plastics 16: 41–43, 70, illus. 1938.

——— and MCKINNEY, L. L. PROTEIN PLASTICS FROM SOYBEAN PRODUCTS: PLASTICIZATION OF HARDENED PROTEIN MATERIAL. Indus. and Engin. Chem. 31: 84–87, illus. 1939.

——— and MCKINNEY, L. L. THE DEVELOPEMNT OF SOYBEAN-PHENOLIC MOULDING PLASTICS. Plastics 4: 93–95, illus. 1940.

——— and MCKINNEY, L. L. PROTEIN PLASTICS FROM SOYBEAN PRODUCTS: INFLUENCE OF PHENOLIC RESINS OR PHENOLIC MOLDING COMPOUNDS ON FORMALDEHYDE-HARDENED PROTEIN MATERIAL. Indus. and Engin. Chem. 32: 1002–1006, illus. 1940.

——— MCKINNEY, L. L., and SUTTLE, W. C. PROTEIN PLASTICS FROM SOYBEAN PRODUCTS: LAMINATED MATERIAL. Indus. and Engin. Chem. 32: 1648–1651, illus. 1940.

——— SUTTLE, W. C., and MCKINNEY, L. L. A SIMPLE FLEXURE-TESTING MACHINE FOR PLASTICS. Amer. Soc. Testing Mater. Bul. 109: 13–16, illus. 1941.

BULL, W. C. SOME OBSERVATIONS ON THE EFFECT OF MOISTURE ON THE QUANTITATIVE EXTRACTION OF LIPIDS FROM SOYBEANS. Oil and Soap 20: 94–96. 1943.

——— and HOPPER, T. H. THE COMPOSITION AND YIELD OF CRUDE LIPIDS OBTAINED FROM SOYBEANS BY SUCCESSIVE SOLVENT EXTRACTIONS. Oil and Soap 18: 219–222, illus. 1941.

——— and WHEELER, D. H. LOW-TEMPERATURE SOLVENT CRYSTALLIZATION OF SOYBEAN OIL AND SOYBEAN OIL FATTY ACIDS. Oil and Soap 20: 137–141, illus. 1943.

CARR, R. B. SOYBEAN VARIETIES IN THE YAZOO-MISSISSIPPI DELTA, 1944–45. Soybean Digest 6 (9): 12–13, illus. 1946.

CARTTER, J. L. EFFECT OF ENVIRONMENT ON COMPOSITION OF SOYBEAN SEED. Soil Sci. Soc. Amer. Proc. 5: 125–130. 1940.

——— EQUIPMENT FOR MAINTAINING CONTROLLED TEMPERATURE AND LOW HUMIDITY IN A SEED STORAGE ROOM. Amer. Soc. Agron. Jour. 34: 1017–1027, illus. 1942.

——— SAVE WEATHER DAMAGED SOYBEANS. U. S. Dept. Agr. AWI–71, 11 pp. 1943.

——— WHAT IS THE U. S. REGIONAL SOYBEAN LABORATORY DOING? Soybean Digest 4 (11): 22, 62. 1944.

——— AND HOPPER, T. H. INFLUENCE OF VARIETY, ENVIRONMENT, AND FERTILITY LEVEL ON THE CHEMICAL COMPOSITION OF SOYBEAN SEED. U. S. Dept. Agr. Tech. Bul. 787, 66 pp., illus. 1942.

——— AND MILNER, R. T. WORK OF THE AGRONOMIC AND ANALYTICAL DIVISIONS OF THE U. S. REGIONAL SOYBEAN INDUSTRIAL PRODUCTS LABORATORY. Amer. Soybean Assoc. Proc. 17: 12–15, illus. 1937.

CIRCLE, S. J., and SMITH, A. K. THE EFFECT OF FORMALDEHYDE ON THE ISOELECTRIC POINTS OF SOME PROTEINS, DETERMINED BY MICROELECTROPHORESIS. Jour. Phys. Chem. 45: 916–930, illus. 1941.

COLLINS, F. I., and KROBER, O. A. SOME FACTORS WHICH AFFECT THE DETERMINATION OF OIL IN SOYBEANS. Oil and Soap 22: 307–310, illus. 1945.

CUTLER, G. H., and PROBST, A. H. GIBSON AND PATOKA SOYBEANS. Ind. Agr. Expt. Sta. Cir. 270, 8 pp., illus. 1942.

——— and PROBST, A. H. EARLYANA SOYBEAN. Ind. Agr. Expt. Sta. Cir. 286, 8 pp., illus. 1943.

DETWILER, S. B., JR. SUPPLEMENT TO BIBLIOGRAPHY ON MOLECULAR OR SHORT-PATH DISTILLATION. Oil and Soap 17: 241–243. 1940.

——— BULL, W. C., and WHEELER, D. H. MOLECULAR DISTILLATION OF A CRUDE SOYBEAN OIL. Oil and Soap 20: 108–122, illus. 1943.

Detwiler, S. B., Jr., and Markley, K. S. bibliography on molecular or short-path distillation. Oil and Soap 16: 2–5. 1939.

——— and Markley, K. S. laboratory-type molecular or short-path still for vegetable and animal fats and oils. Indus. and Engin. Chem., Analyt. Ed. 12: 348–350, illus. 1940.

——— and Markley, K. S. smoke, flash, and fire points of soybean and other vegetable oils. Oil and Soap 17: 39–40. 1940.

Dollear, F. G., Krauczunas, P., and Markley, K. S. composition of a soybean oil of abnormally low iodine number. Oil and Soap 15: 263–264. 1938.

——— Krauczunas, P., and Markley, K. S. the chemical composition of some high iodine number soybean oils. Oil and Soap 17: 120–121. 1940.

Earle, F. R., and Detwiler, S. B., Jr. wax constituents of the winterizer press cake of soybean oil. Oil and Soap 18: 117–119, illus. 1941.

——— and Milner, R. T. the occurrence of phosphorus in soybeans. Oil and Soap 15: 41–42. 1938.

——— and Milner, R. T. study of the kaufmann method for determining iodine numbers. Oil and Soap 16: 69–71. 1939.

——— and Milner, R. T. a crystallization method for the determination of saturated fatty acids in soybean oil. Oil and Soap 17: 106–108. 1940.

Earley, E. B. minor element studies with soybeans: i. varietal reaction to concentrations of zinc in excess of the nutritional requirement. Amer. Soc. Agron. Jour. 35: 1012–1023, illus. 1943.

——— and Cartter, J. L. effect of the temperature of the root environment on growth of soybean plants.' Amer. Soc. Agron. Jour. 37: 727–735, illus. 1945.

Goss, W. H. modern practice in solvent extraction. Chem. and Metall. Engin. 48: 80–84, illus. 1941.

——— technological problems in processing soybeans. 1. the continuous-pressing method. Soybean Digest 1 (8): 2–3, illus. 1941.

——— technological problems in processing soybeans. 2. the solvent process. Soybean Digest 1 (9): 2–3, illus. 1941.

——— technological problems in processing soybeans. 3. solvents for soybean oil extraction. Soybean Digest 1 (10): 4–5. 1941.

Henson, P. R. southern soybean program of the u. s. regional soybean laboratory. Soybean Digest 5 (11): 47, 60. 1945.

——— the southern regional soybean variety program. Soybean Digest 6 (11): 37–39, illus. 1946.

——— soybeans for the south. U. S. Dept. Agr. Yearbook 1943–47: 338–343. 1947.

Hopper, T. H. report of the soybean analysis committee. Oil and Soap 18: 132–133. 1941.

——— regional lab winds up 5 years. Soybean Digest 1 (11): 7. 1941.

Houseman, E. E., Weber, C. R., and Federer, W. T. pre-harvest sampling of soybeans for yield and quality. Iowa Agr. Expt. Sta. Res. Bul. 341: [809]–826, illus. 1946.

Hughes, H. D. soybeans through 30 years at the iowa station. Iowa Agr. Expt. Sta. Ann. Rpt. 1942: [19]–26, illus. 1942.

Johnstone, H. F., Spoor, I. H., and Goss, W. H. properties of soybean oil-solvent mixtures. Indus. and Engin. Chem. 32: 832–835, illus. 1940.

Kalton, R. R. factors affecting soybean yields. Soybean Digest 6 (5): 18–19, illus. 1946.

——— and Eldredge, J. C. the effect of simulated hail injury to soybeans. Soybean Digest 6 (3): 14–15. 1946.

——— and the Iowa Agricultural Experiment Station. iowa soybean variety tests 1939–1945. Iowa Agr. Expt. Sta. leaflet Agronomy, v. 41, 6 pp. 1946. [Mimeographed.]

King, B. M., and Allen, D. I. soybean production in missouri. Mo. Agr. Expt. Sta. Bul. 445, 31 pp., illus. 1942.

Kraybill, H. R., Smith, R. L., and Walter, E. D. the isolation of sucrose from soybeans. Amer. Chem. Soc. Jour. 59: 2470–2471. 1937.

——— Thornton, M. H., and Eldridge, K. E. sterols from crude soybean oil. Indus. and Engin. Chem. 32: 1138–1139. 1940.

Krober, O. A. kjeldahl calculator. Amer. Assoc. Cereal Chem. Trans. 3 (3): 169–172, illus. 1945.

——— and Collins, F. I. effect of relative humidity on the determination of oil in soybeans. Oil and Soap 21: 1–5, illus. 1944.

——— Collins, F. I., and Demlow, M. J. sampling soybeans for analysis. Oil and Soap 22: 194–196, illus. 1945.

Lewis, A. J. comparative durability of soybean and other oil varnishes. Paint, Oil, and Chem. Rev. 102 (9): 9–11. 1940.

——— comparative durability of soybean, soybean-perilla, and linseed oil paints. Oil, Paint, and Drug Rptr. 140 (8): 5, 38. 1941.

Lewis, A. J., gloss retention and wood protection merits of phenolic resin-soybean oil varnishes. Paint, Oil, and Chem. Rev. 104 (2): 7–8. 1942.
——— and Markley, K. S. soybean oil varnishes. Paint, Oil, and Chem. Rev. 99 (26): 5, illus. 1937.
——— and Markley, K. S. the utilization of soybean oil in paints and varnishes. Paint, Oil, and Chem. Rev. 100 (22): 8–9. 1938.
McKinney, L. L. soy meal in plastics. Soybean Digest 2 (8): 4–5, 11, illus. 1942.
——— and Brother, G. H. soybeans in plastics. flow properties of a phenolic plastic modified with formaldehyde-hardened soybean meal. Mod. Plastics 18 (9): 69–71, illus. 1941.
——— Deanin, R., Babcock, G., and Smith, A. K. soybean-modified phenolic plastics. Indus. and Engin. Chem. 35: 905–908, illus. 1943.
Majors, K. R., and Hopper, T. H. a shaping lathe for graphite electrodes used in spectrochemical analysis. Indus. and Engin. Chem., Analyt. Ed. 13: 647–648, illus. 1941.
——— and Milner, R. T. relation between the iodine number and refractive index of crude soybean oil. Oil and Soap 16: 228–231, illus. 1939.
Markley, K. S., and Goss, W. H. soybean chemistry and technology. 261 pp., illus. Brooklyn, N. Y. 1944.
May, O. E. proposed research program of the regional soybean industrial products laboratory. Oil and Soap 13: 229–231. 1936.
——— research program of the regional soybean industrial products laboratory. Amer. Soybean Assoc. Proc. 16: 3–6. 1936.
——— the u. s. regional soybean industrial products laboratory, urbana, ill. Amer. Soybean Assoc. Proc. 17: 10–11. 1937.
——— federal soybean research. Sci. Teacher 5 (3): 1–3, 20; (4): 8, 9, 20, 23. 1938.
——— work of the u. s. regional soybean industrial laboratory. Farm Chemurg. Jour. 1 (3): 52–59. 1938.
Milner, R. T. progress of the u. s. regional soybean industrial products laboratory. Amer. Soybean Assoc. Proc. 18: 3–5. 1938.
——— report of the soybean analysis committee of the american oil chemists' society. Oil and Soap 15: 214. 1938.
——— report on sodium and potassium. Assoc. Off. Agr. Chem. Jour. 21: 356. 1938.
——— recent progress of the u. s. regional soybean industrial products laboratory. Amer. Soybean Assoc. Proc. 19: 56–60. 1939.
——— report of the soybean analysis committee 1938–39. Oil and Soap 16: 129–131, illus. 1939.
——— news from the regional soybean laboratory. Amer. Soybean Assoc. Proc. 20: 36–38, illus. 1940.
——— report of the soybean analysis committee 1939–40. Oil and Soap 17: 126. 1940.
——— soybean oil traffic paint probable. Soybean Digest 1 (2): 2. 1940.
——— u. s. regional soybean industrial products laboratory. Phi Lambda Upsilon Register 26 (1): 6–14. 1941.
Morse, W. J., and Cartter, J. L. improvement in soybeans. U. S. Dept. Agr. Yearbook 1937: 1154–1189, illus. 1937.
——— and Cartter, J. L. soybeans: culture and varieties. U. S. Dept. Agr. Farmers' Bul. 1520, 38 pp., illus. 1939.
Nagel, R. H. combined support and water supply for condensers. Chem. Analyst 29 (2): 44–45, illus. 1940.
——— Becker, H. C., and Milner, R. T. the solubility of some constituents of soybean meal in alcohol-water solutions. Cereal Chem. 15: 766–774, illus. 1938.
——— Becker, H. C., and Milner, R. T. some physical factors affecting the dispersion of soybean proteins in water. Cereal Chem. 15: 463–471. 1938.
Paschke, R. F., and Wheeler, D. H. formation and decomposition of peroxides of unsaturated fat esters. Oil and Soap 21: 52–57, illus. 1944.
Probst, A. H. border effect in soybean nursery plots. Amer. Soc. Agron. Jour. 35: 662–666. 1943.
——— influence of fertilizer, fertilizer placement, soil moisture content, and soil type on the emergence of soybeans. Amer. Soc. Agron. Jour. 36: 111–120, illus. 1944.
——— influence of spacing on yield and other characters in soybeans. Amer. Soc. Agron. Jour. 37: 549–554. 1945.
——— and Cartter, J. L. a portable soybean nursery thresher and its operation. Amer. Soc. Agron. Jour. 33: 673–675, illus. 1941.
——— and Cutler, G. H. indiana soybean variety tests, 1938–44. [Ind.] Agr. Expt. Sta. Mimeo. No. 2, 6 pp. 1945. [Mimeographed.]
Ramstad, P. E., and Geddes, W. F. the respiration and storage behavior of soybeans. Minn. Agr. Expt. Sta. Tech. Bul. 156, 54 pp., illus. 1942.

Scholfield, C. R., and Bull, W. C. relation between the fatty acid composition and the iodine number of soybean oil. Oil and Soap 21: 87-89, illus. 1944.

Slatensek, J. M., and Kiesselbach, T. A. edible soybeans in nebraska. Nebr. Agr. Expt. Sta. Bul. 356, 10 pp., illus. 1944.

Smiley, W. G., and Smith, A. K. electrode polarization in dielectric constant measurements. Amer. Chem. Soc. Jour. 64: 624-628, illus. 1942.

Smith, A. K. soybean protein. Soybean Digest 2 (9): 4-5. 1942.

——— and Circle, S. J. peptization of soybean proteins. the extraction of nitrogenous constituents from oil-free meal by acids and bases with and without added salts. Indus. and Engin. Chem. 30: 1414-1418, illus. 1938.

——— and Circle, S. J. soybean protein. precipitation from water and alkaline dispersions by acids and by electrodialysis. Indus. and Engin. Chem. 31: 1284-1288, illus. 1939.

——— Circle, S. J., and Brother, G. H. peptization of soybean proteins. the effect of neutral salts on the quantity of nitrogenous constituents extracted from oil-free meal. Amer. Chem. Soc. Jour. 60: 1316-1320, illus. 1938.

——— Handler, P., and Mrgndich, J. N. the reaction of formaldehyde with amino acids: x-ray diffraction patterns. Jour. Phys. Chem. 44: 874-880, illus. 1940.

——— and Max, H. J. soybean protein dispersions in formaldehyde solutions. preparation and application. Indus. and Engin. Chem. 32: 411-415, illus. 1940.

——— and Max, H. J. soybean protein. adhesive strength and color. Indus. and Engin. Chem. 34: 817-820, illus. 1942.

——— Max, H. J., and Handler, P. the dispersion of protein in aqueous formaldehyde solutions. Jour. Phys. Chem. 43: 347-357, illus. 1939.

Stewart, H. W., and Wheeler, D. H. the melting points of binary mixtures of oleic, linoleic, and linolenic acids. Oil and Soap 18: 69-71, illus. 1941.

Thornton, M. H., and Broome, F. K. determination of choline. a photometric modification of beattie's method. Indus. and Engin. Chem., Analyt. Ed. 14: 39-41, illus. 1942.

——— and Kraybill, H. R. phosphatides from soybean oil. Indus. and Engin. Chem. 34: 625-628, illus. 1942.

——— Kraybill, H. R., and Broome, F. K. sterol glucosides from cottonseed oil. Amer. Chem Soc. Jour. 63: 2079-2080. 1941.

——— Kraybill, H. R., and Mitchell, J. H., Jr. sterol glucosides from expressed soybean oil. Amer. Chem. Soc. Jour. 62: 2006-2008. 1940.

Walter, E. D. genistin (an isoflavone glucoside) and its aglucone, genistein, from soybeans. Amer. Chem. Soc. Jour. 63: 3273-3276, illus. 1941.

Weber, C. R. lincoln—a new variety high in yield and oil content. Soybean Digest 4 (5): 6-7, illus. 1944.

——— more, better soybeans. Farm Sci. Rptr. 5 (1): 3-6, illus. 1944.

——— and Kalton, R. R. iowa soybean variety tests 1939-1946. Iowa Agr. Expt. Sta. leaflet Agronomy, v. 59, 8 pp., illus. 1947. [Mimeographed.]

Weiss, M. G. field seed cleaner for soybeans. Amer. Soc. Agron. Jour. 33: 849-850, illus. 1941.

——— inheritance and physiology of efficiency in iron utilization in soybeans. Genetics 28: [253]-268, illus. 1943.

——— and Cox, G. M. balanced incomplete block and lattice square designs for testing yield differences among large numbers of soybean varieties. Iowa Agr. Expt. Sta. Res. Bul. 257, pp. [293]-316, illus. 1939.

——— Wilsie, C. P., Lowe, Belle, and Nelson, P. M. vegetable soybeans. Iowa Agr. Expt. Sta. Bul. P39, pp. [383]-395, illus. 1942.

Williams, L. F. the breeding work of the u. s. regional soybean laboratory. Soybean Digest 4 (11): 34, 64. 1944.

——— off-colored seeds in the lincoln soybean. Soybean Digest 5 (11): 50, 61, illus. 1945.

Woodworth, C. M., and Williams, L. F. recent studies in the genetics of the soybean. Amer. Soc. Agron. Jour. 30: 125-129, illus. 1938.

——— and Williams, L. F. lincoln soybeans. Ill. Univ. AG-1246, 9 pp. 1945. [Mimeographed.]

O